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CHAPTER I

THE MATERIAL FOR MAP CONSTRUCTION SURVEYS

The Shape of the Earth.—The shape of the earth is very nearly, but not quite, that of a ball or sphere. The earth really has a shape of its own called the *geoid*, and the geoid is almost exactly the shape of a ball flattened at opposite "poles"—the figure known to mathematicians as a *spheroid*. For some very precise investigations we deal with the geoid. Where less accuracy is sufficient, as in making even the best maps, the spheroidal figure is taken. For our elementary purposes here the ball is near enough to the truth: that is to say that we shall be concerned mainly with rough maps, in which we shall have greater errors than those due to thinking about a sphere instead of a spheroid, much less a geoid.

The earth spins round an axis, the axis passing through its centre; the condition is the same as that of a ball transfixed by a knitting needle which passes through the centre of the ball. The needle emerges at the surface of the ball at two points, called, in the case of the earth, North and South Poles to distinguish them. If the earth were cut in two at right angles to the axis through the centre, the line which would be drawn round it by the cutting plane is called the *Equator*.

How the shape of the earth was discovered will be explained later on (page 19). The statement of the result

may be accepted for the present, and we come next to the important fact that man lives and moves on the surface of the earth ball. This surface is made up of two parts which are quite distinct, because one is a rough solid surface, and the rest is liquid. Man was originally confined to the solid or *land* part on which he can get about on his own feet, but in very early times he invented an apparatus called a boat, by means of which he can also get about on the liquid or *sea* part of the surface. For a long time he has been able to travel and to transport his goods more easily and cheaply on sea than on land. His efforts to penetrate or move about below the surface, or in the atmosphere which rests upon it and encloses it, have met with no success until recent years, and the results are still very crude.

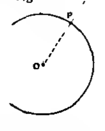
The Force of Gravity.—Everything on the surface of the earth retains its position there because of the action of a force called gravity. The force of gravity acts, so far as we know, throughout all space; it controls the positions and movements of the remotest stars. To us it is chiefly important to know that it attracts bodies on the earth's surface towards the centre of the earth. Wherever a body may be on the earth's surface there is a force pulling it towards the earth's centre, and unless this force is met the body will "fall," that is move towards the centre of the earth or *downwards*. If the force of gravity is met not directly but obliquely, then the body will slide partly downwards and partly sideways or "down the slope."

This is important because it enables us to find, at any point on the earth's surface, a fixed direction, which we shall presently see is very useful in map making. If we hang a bullet at one end of a string, and fix the other end of the string, the bullet will try and get to the earth's centre. The string, having no stiffness, will take the direction of the pull of the bullet, and so we know the direction of the earth's centre from the point of observation. This device is what is called the plumb line, and the

direction taken by the plumb line is called the *vertical* direction

Let O (Fig 1) be the earth's centre, P a point on its surface, then gravity acts in the direction P O, and a plumb-line at P will reveal the direction P O To keep himself from tumbling over, a man at P stands in the "erect" position, the vertical line P O passes between his feet and through his head The point Z over his head is called the zenith

Fig 1



A more useful device for map making purposes gives us the direction of direct resistance to gravity—that at right angles to it A surface following this direction is said to be level or *horizontal*, the instrument is called a spirit level It consists of a slightly bent tube (Fig 2) mostly filled with spirit (the black part), but with a bubble of air left in it Now, bulk for bulk gravity acts more strongly on the liquid than it does on the air, or as we say, the spirit is *heavier* than the air So the spirit gets nearer the centre of the earth, and the air bubble comes to the top which is further away from it, the bubble is, in fact, always at the highest part of the tube If the end A, or the end B, is tipped up, the bubble runs to the upper end but if A and B are at the same level or horizontal, the bubble stands in the middle of the tube In this way we can always place the tube, or anything it is fixed to, in the horizontal plane

Fig 2

The Sky line and Horizon — At whatever point we stand on the earth's surface our vision is limited in certain directions Around is a region which is obviously a part of the earth's surface, every point on it being near and accessible, and above is the space we call the sky, as

obviously not a part of the earth's surface. The bounding line between the two we call the *sky line*. As we move about from point to point on the earth's surface we find the sky line constantly changing: part at least of the area visible from one point is invisible from another, and from this in turn some part becomes visible which was invisible before. On land the sky line is usually quite irregular; we see hills in one direction and valleys in another, and between our point of observation and the sky line there are often *slopes*, *i.e.*, surfaces which are not horizontal but must be descended or ascended with or against the force of gravity. But the sea surface being liquid cannot have any slopes, for if such existed the water would run down them, and there is no such general movement in oceanic waters. Now observation shows that

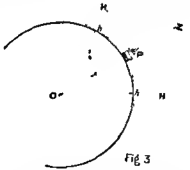


Fig. 3

the sky line at sea is always a circle with the observer at the centre, and further that the radius of the circle (or the distance of the sky line) is always the same in all parts of the ocean provided the height of the observer's eye above the sea remains the same. Thus if the eye is six feet above the sea, the sky line is three miles distant; if twenty feet, five miles; if fifty feet, seven and a half miles, and so on. This shows first that the surface of the ocean is convex

and secondly that it is everywhere of the same convexity, or that (so far as appears from observations of this degree of accuracy) the earth is a sphere

The sea sky line having a definite relation to the shape of the earth is usually called the *visible horizon* If the observer's eye is above the level of the sea say on board ship, the visible horizon will evidently be below the horizontal plane (sometimes called the *sensible horizon*) passing through his eye The angle of depression is called the *dip* of the horizon (See Fig 3, in which P is the point of observation, O Z the vertical line H H the horizontal plane, and *h h* the visible horizon The angle H P *h* is the dip)

Principles of Surveying The Theodolite —The first step in map-making is to describe and record accurately the positions of things seen within the sky line from any point We can only do this with reference to some known or fixed directions It has already been explained how by means of plumb-line or spirit level we can always find the direction of the vertical line or the horizontal plane at a point In practice this is done by an instrument such as the *Theodolite* illustrated in Fig 4 A A is a plate mounted upon legs, and upon it rests

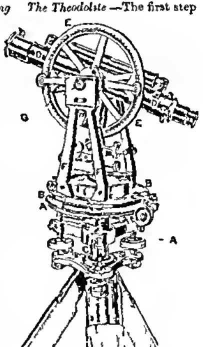


Fig 4

a plate B B, held centrally in place by a round spindle at C at right angles to both plates If A A and B B are adjusted *by means of spirit levels so as to be horizontal, the spindle* C will be vertical, and the plate B B can be turned round on A A in any direction, always remaining horizontal Let D D be a telescope, fixed to a stand F F on B B but free to move round on a horizontal pivot G E E is a circle fixed to D D, having angles (degrees, minutes, seconds) marked on it, and so arranged that the angle through which the telescope is moved up or down round the pivot G can be read off Then the instrument may be so adjusted that when *B B is level or horizontal, and the reading on E is 0°, the* telescope D is also level If we turn B B round on C all points on the horizontal plane of the place where the instrument is set up, in different directions, will appear in the telescope

Altitude and Azimuth.—Now suppose we point the telescope at a particular object say the summit of a mountain then we shall have had to turn it round G through some angle which can be read off on E This angle above the horizontal plane is called the *Altitude* of *the summit of the mountain as seen from the point of* observation, and it gives the first means of recording the apparent position Altitude, then, is angular distance above the horizontal plane

By determining the altitude of the object we have not however completely fixed its apparent position for it is clearly possible to rotate the plate B B on A A round the pivot G without touching the telescope this is to say there is any number of points, in different directions having the same altitude It becomes necessary to seek for a fixed direction which can always be easily ascertained and to reckon the difference of direction of (say) the mountain top from that standard Fortunately again there is a standard direction which can always be found (though not so easily as the horizontal plane)—the direction of *north* and

south The angle from north and south is measured by marking degrees and minutes on the circular edge of the plate A A and making a mark on the edge of B B so that if we first turn the telescope so as to point north or south and read the scale on A A, and then turn it round to point at the object and read the scale again, the difference of the readings gives the direction, or, as it is called, the *Azimuth* of the point Sometimes azimuth is reckoned from north or south in 'points instead of degrees, there being 32 points in the circle Each point is distinguished by a name, north and south are two, at right angles to these we have east and west, and the intermediate points are named by combinations of these words as shown in the "Compass Card"

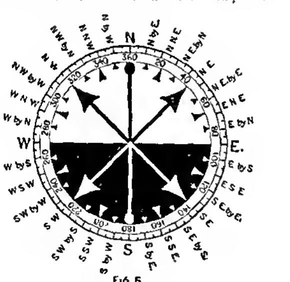


Fig 5

of Fig 5 Thus an azimuth of 45° round from north towards east is north-east of 135 south-east, and so on The system of points was, and still is to a great extent, used by sailors in laying the courses of ships, but for accurate

navigation, and still more for any kind of map or chart making, the division of the circle into ordinary angular measure is much more precise

When the altitude and azimuth of a point seen from a place of observation have been determined, the apparent position of that point is completely fixed. Suppose we are able to clamp the telescope at the given readings on the vertical and horizontal scales, it can neither be moved up or down or turned round—it can only point in the one determined direction and in no other. If, for example, we say that seen from a place A the point B has altitude 21° and azimuth N 15° E then the apparent position of B is known, and can be found at any subsequent time by an observer who sets up his theodolite at A, provided B is a fixed point

In the case of celestial bodies, such as the sun or stars, the positions are constantly changing, and so altitudes and azimuths vary. Observations of these altitudes and azimuths are very important, but it is to be noted that the *time* of observation must always be recorded

Distance.—When the observer at A has completed his observations of the points on the earth's surface which are visible from A, he has a series of records of altitudes and azimuths of such points as B, C, D, E, but he has no information about the *distances* of these points. In order to fix the points finally upon a map he must determine these distances, and he may do so by actual measurement of the lengths of the lines A B, A C, A D, A E. By way of illustration let us take the case of a level field, and suppose the theodolite set up in the middle of it. Since the field is level altitudes will all be the same and they may be left out of account. We may have a record such as this.—From A

Azimuth of	B	north	10°	east,	distance	150	yards
"	C	"	75°	"	"	200	"
"	D	"	150°	"	"	75	"
"	E	"	100°	west	"	180	"

If B C D E represent corners of the field and the fences run straight between these points we have all the material necessary for making a plan or map, as Fig 6.

Triangulation.—But measurements along the ground are not readily made with accuracy, especially if the ground is uneven; it is much easier to get good measurements of angles with the theodolite. Surveyors therefore find the distances of points, where possible, by the following method.

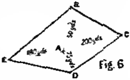


Fig. 6

Two points A and B (Fig 7) are selected visible from each other and separated by ground which is as nearly level as may be. The distance A B is measured with all possible accuracy, and then the azimuthal angles of points C D E supposed to be visible from both A and B are read off. In the triangle A B C we then know the side A B and the angles C A B and A B C; in A B D we know A B and the angles D A B and D B A; in A B E we know A B and the angles E A B and E B A. But by plane trigonometry we can then *calculate* the third angle and the lengths of the two remaining sides of each triangle, there is no necessity for further measurement. Again suppose F and G to be two points visible from A and D and A and E respectively but invisible from B: we may take observations of azimuth at A D and E and so in the triangle A F D we know the side A D and the angles F A D and A D F, and in A G E we know A E and the angles G A E and G E A and we can find the angles at F and G, and the sides F D, F A, G A, G E. This process can be continued indefinitely till we have built up a network of triangles extending over an area of any size, there is only one measurement of length,

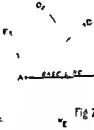


Fig 7

viz., A B, which is called the *base-line*, everything else is done by angular measurements with the theodolite or some similar instrument. The method is known as *Triangulation*, and it is that upon which most standard surveys depend.

The weak point of triangulation is that everything depends upon the accuracy of the measurement of the base-line and of the angles, for it will be seen that each triangle must be affected by the errors of all those which come between it and the original points on the base line, and such errors will accumulate rapidly unless extreme care is taken. In a first class survey the triangles which directly depend upon the base line are very large, the sides of the triangles being many miles in length, and angles are measured with the highest possible degree of accuracy. This system is known as *primary* triangulation, and each of the primary triangles is then sub-divided into smaller triangles forming the *secondary* triangulation, in which a less degree of precision is sufficient, because errors cannot affect anything outside one primary triangle. Similarly, secondary triangles are sub-divided by *tertiary* systems, within which quite rough measurements, or even sketches without measurements at all, may be sufficient.

Traversing.—In some parts of the world, such as regions of mountain ranges with inaccessible peaks separated by deep narrow valleys or of unbroken plain covered with dense forest, triangulation is difficult or impossible through the want of intervisible points. In this case another method is resorted to which involves an increased number of measurements of distance.

Suppose B (Fig. 8) is or can be made visible from A, C from B, D from C, and so on. Then the azimuth of B from A is observed and the distance A B measured, thus the position of B is found. Similarly C can be found from B, D from C, and so on. Such a survey is, if possible, arranged so that it begins and ends at the same point A. The errors of the survey will result in the difference that

when the surveyor has actually returned to his starting point A his survey has only brought him to some other point represented by A The discrepancy A A is called the *closing error* of the survey and the errors (here as elsewhere to be distinguished from blunders or mistakes) can be distributed by the mathematical theory of probabilities—which in practice yields some fairly simple geometrical constructions —in such a way as to give a high degree of accuracy The survey

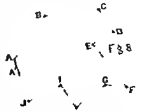


Fig 8

need not necessarily end where it began but in order to distribute the errors the starting point A and the finishing point A should either be identical or be such that their relative positions can be accurately determined independently This method of surveying is known as *Traversing*

Determination of Heights—Next to the determination of position come the questions of height and slope Here accurate work is best done by means of the theodolite or similar instrument Let A be a point on a slope (represented in Fig 9) and suppose the theodolite to be set up at A and levelled the telescope being 5 feet above the ground (its height being measured at A by a graduated vertical rod) Then if the telescope is horizontal the point B seen through it must be 5 feet higher than A Similarly if the theodolite is set up at B C is 5 feet higher than B and so on

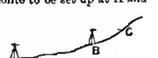


Fig 9

Another method is illustrated in Fig 10 Suppose A and B to be two points on the same level and the distance A B to have been ascertained by measurement Then if we measure the altitudes of points C D and E on the slope from A and B we get two angles and a side of each of the triangles A B C, A B D and A B E We can solve

these triangles and allowing for the height of the instrument calculate the vertical heights C C', D D, E E

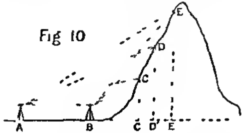


Fig 10

Datum Level—Heights are usually reckoned from an arbitrary zero called mean sea-level supposed to represent the average level of the sea at some point on the coast of a district surveyed The actual average level of the sea is very difficult to determine accurately, but so long as a uniform starting point is agreed upon the standard of reference is not of first importance in map construction The *datum* of the British Ordnance Survey is 0 65 feet below mean sea level at Liverpool

Slopes—Having ascertained the difference in level and the distance between two points the average slope of the ground between them may be conveniently expressed in either of two ways

Let A and B (Fig 11) be the two points A *h* the horizontal plane then we may either measure the angle B A *h* and say the slope is so many degrees or we may divide the total difference in height B *h* by the distance A *h* and say the gradient is one foot (or other unit) for so

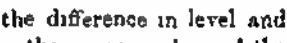


Fig 11

many feet (or other unit) of distance The following table gives a few equivalent examples —

A slope of 2° is equivalent to a gradient of	1 in 28	
„ 5° „ „ „	1 in 11	
„ 10° „ „ „	1 in 6	
„ 20° „ „ „	1 in 3	

Horizontal Equivalents —For reasons which will appear presently, the equivalent length A *h* of the slope A B projected on the horizontal plane is important This length is usually expressed in terms of the height B *h* and the angle of slope A Thus if B *h* is unity (feet, yards, etc) and A is 1°, A *h* is 57 3, the co-tangent of the angle, and for any value of B *h* we can get the corresponding length of A *h* for that slope by simply multiplying by 57 3 For different degrees of slope we get as multipliers —

1°	57 3	10°	5 7
2°	28 6	15°	3 7
3°	19 1	20°	2 7
4°	14 3	25°	2 1
5°	11 4	30	1 7

It will be seen that for the more gentle slopes at least these horizontal equivalents are proportional to the angle of slope, and we accordingly get the approximate rule

$$\text{H E} = 57\ 3^{*} \times \frac{\text{V I}}{\text{D}}$$

Where H E is the horizontal equivalent (A *h*)

V I is the vertical interval (B *h*)

D is the slope in degrees (or altitude) (Angle A)

Latitude and Longitude —A system of triangulation or traversing can be started at any point on the surface of the earth, and may theoretically be extended continuously so as to cover the whole surface But in practice this is impossible An island in mid-ocean may be completely surveyed, but it is impossible to execute a triangulation

*In military work distances are usually reckoned in yards and heights in feet The value 57 3 must therefore be divided by 3 = 19 1

over the sea to connect it with the nearest continent It would be a difficult task to connect a survey of, say, South Africa with one of the Argentine, or of India Hence, unless we can find some independent means of fixing at least one of the points on each survey, we have no means of saying to what part of the earth it refers A Chinaman presented with a sheet of the one inch Ordnance map of this country might guess it referred to a survey of some part of the British Isles, but he would probably be quite unable to find out what part

Position on the earth's surface is defined by a system of cross angles corresponding or analogous to altitude and azimuth the centre of the earth corresponding similarly to the point of observation, the axis to the vertical line and the plane of the equator to the horizontal plane If O (Fig 12) represents the centre of the earth, N and S the north and south poles O Q the edge of the equatorial plane then a point P may be partly defined by the angle P O Q which is called the *Latitude* All points having the same latitude evidently lie on a circle (P P T, U V W, Fig 13 in which N is the north pole) the centre of which is on the earth's axis Such a circle is called a *parallel of latitude* The second series of angles is obtained by considering planes at right angles to the equator passing through the earth's axis The plane of the paper

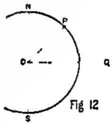


Fig 12

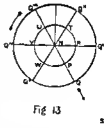


Fig 13

is such a plane in Fig 12 and Q N Q^{III} Q N Q^{IV} Q^{I} N Q^{V} represent the edges of similar planes in Fig 13 If the position of this plane passing through a point P as well as the latitude of P) is known then P is fixed on the surface of

the earth, just as any point seen from it is fixed by altitude and azimuth. The angles between the meridians passing through different points as P, R, T, U, V, W (Fig. 13) are called angles of *Longitude*, thus P N R is the longitude of R with reference to P, P N T that of T and so on. These planes cut the surface of the earth in circles having for centres the centre of the earth, and passing through, and intersecting at, the north and south poles. N P Q S in Fig. 12 is half such a circle, and N P Q, N R Q', etc. in Fig. 13 represent quadrants of these circles. The semicircles are called *Meridians*, and as the meridian line passing through any point P also passes through the north and south poles, its direction is that of north and south: hence its selection as the zero from which azimuth is reckoned (page 8).

Circles drawn on a sphere which have their centres at the centre of the sphere are the largest circles which can be drawn on the surface and they are all of the same size. They are called *Great Circles*, and an important property of the great circle passing through any two points on a sphere is that its arc follows the shortest possible course joining the two points. The shortest route between two points on the ocean is the great circle route, hence the importance of great circle sailing in modern navigation. Any circle on the sphere whose centre is not the centre of the sphere is called a *Small Circle* and the smaller the circle the greater the distance of its centre from that of the sphere.

The equator is clearly a great circle, all other parallels of latitude are equally clearly small circles. Latitudes are therefore reckoned from the equator to the north pole (lat. 90° N.), and the south pole (lat. 90° S.). All meridians are great circles and there is therefore no one meridian from which longitudes will naturally be reckoned. Different countries have used the meridian passing through their capital or other point as the zero of longitude or *prime*

meridian but there is now increasing agreement to accept the meridian of Greenwich as an international standard. Thus we say that Cairo or Petrograd are in (roughly) longitude 30° E, Washington in longitude 75° W, or Bering Strait in longitude 170° W.

Determination of Latitude.—Direct observation of latitude and longitude is of course impossible, since we cannot set up a theodolite at the earth's centre on the plane of the equator and measure the necessary angles. The question becomes one of deducing the latitude or longitude of a point from the practicable observations of altitude or azimuth or of time.

A simple way of making an approximate determination of latitude depends upon the observation of the altitude of the point in the heavens about which the heavens appear to rotate. All the fixed stars are at a practically infinite distance from the earth, hence we may think of them as being all at an equal distance or dotted about upon the inside surface of a hollow sphere of infinite radius which has the earth (a mere point) at its centre. As the earth rotates this celestial sphere will appear to all observers on the earth to be rotating about two poles which are the points where the earth's axis produced infinitely in both directions meets the celestial sphere.*

Let O (Fig. 14) be the earth's centre, N P Q a quadrant of a meridian, P the position of the observer in the latitude P O Q, H H the horizontal plane at P. Then at N, the north pole, the pole of the heavens is overhead at an infinite distance away in the direction S'. But seen from P the pole appears in the direction S'' again at an

*The positions of the stars on the celestial sphere are described by a system of cross angles analogous to latitude and longitude. The plane of the terrestrial equator extended infinitely to the celestial sphere cuts it in the *Equinoctial Line*. Angles reckoned north and south from the equinoctial (at the centre) are called angles of *Declination*. The angles corresponding to longitude are known as angles of *Right Ascension* and are reckoned from the *First Point of Aries*, the celestial Greenwich.

infinite distance away The lines $ON S^I$ and $P S^{II}$ meet therefore at an infinite distance from the earth, and it follows that they are parallel and if they are parallel the angles $H P S^{II}$ and $P O Q$ are equal Hence we have the very important result that *the altitude of the celestial pole at any point on the earth's surface is equal to the latitude of that point* We recommend the reader to make himself specially familiar with this proposition as it clears the way to an understanding of many of the principal facts of astronomy and mathematical geography

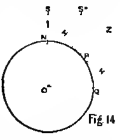


Fig 14

One of the bright fixed stars of the northern hemisphere has its position very near the north pole of the heavens describing a circle of only 1 10 radius For quite rough purposes it is therefore sufficient to say that the altitude of the *Pole Star* is equal to the latitude Accurate determinations of latitude are made by observing the altitude of the pole star and applying suitable corrections for its position in its small circular path at the moment of observation For methods of determining latitude by observation of other stars or of the sun the reader is referred to books on astronomy or navigation

Size and Shape of the Earth—If we determine the latitudes of two points on the same meridian i e north and south of one another and then measure the distance on the earth's surface between them we get a measure of the size of the earth In Fig 15 we know the arc P R by measurement and the angle P O P the difference of the latitudes and we can calculate O P or O R If the distance P R were the same in all latitudes for the same value of

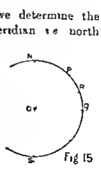


Fig 15

the angle P O R, then O P or O R would be constant the meridian would be of constant radius or a circle and the figure of the earth (obtained by spinning the meridian about the axis N O S) a sphere As a matter of fact the length of a degree of latitude increases somewhat from the equator towards the poles the lengths being approximately —

Latitude	Length (Miles)	Latitude	Length (Miles)
0°— 1°	68 7	60 —61°	69 2
15 —16°	68 7	75°—76°	69 4
30 —31°	68 9	89°—90°	69 4
45°—46°	69 0		

Hence the radii diminish with increasing latitude, the equatorial radius being 3,963 miles, and the polar radius 3,950 miles The average length of a degree of latitude being 69 miles, the radius of the equivalent circular meridian or of the spherical earth, is 3 955 miles and the circumference 24 840 miles It is useful in *reckoning distances, or constructing rough scales for such maps as are published without them,* to bear in mind that a degree of latitude is about 70 miles in length Main land in the Shetland Islands, or Cape Farewell in Greenland or Petrograd lies in latitude 60° N just 700 miles north of the Lizard which is in latitude 50° N

Determination of Longitude —Referring again to Fig 13, let the observer suppose himself placed at the north pole of the heavens He will see that the earth rotates from west to east (as shown by the arrow), and it does so at a uniform rate Let S represent a fixed star, placed on the celestial sphere (in the direction indicated) at an infinite distance from the earth It will be clear that at some instant during a rotation of the earth N P Q and S will all be in one plane as shown in the figure As rotation proceeds the star S is as it were left behind, and appears to move westward but after one complete rotation (no more and no less) it will again be in the same plane as N P

and Q or *on the meridian* But as the rate of rotation is uniform, successive *Transits* of a fixed star across any meridian occur at precisely equal intervals of time From this we derive one of the most important methods of measuring time, the interval between two transits of a fixed star is known as a *sidereal day* For most purposes it is convenient to take time from the sun rather than a fixed star the sun being on the meridian in the middle of its light-giving day, but complications are introduced because the sun does not appear as a fixed star, but is constantly changing its apparent position as the earth goes round it The sun itself keeps *apparent solar time*, and certain irregularities in its movement are averaged out by the system known as *mean solar time*, according to which ordinary clocks and watches are regulated The mean solar day is longer than the sidereal day by about four minutes the effect being the same as if the star S (Fig 13) had progressed in the same direction as that in which the earth is rotating through an angle, such that after making a complete rotation (a sidereal day) the earth had to go on rotating for four minutes more in order to "catch up" S and get it again on the meridian N P Q

Since the rate of the earth's rotation is uniform, it appears that there is a close relation between time and longitude Suppose P, R T, U, V and W (Fig 13) to differ equally by 60° in longitude, then in the 24 hours between two transits of S across the meridian of P, the transit across the meridian of W will occur $\frac{60^\circ}{360^\circ} \times 24$, or 4 hours later than at P, that at V $\frac{120^\circ}{360^\circ} \times 24$, or 8 hours later, and so on 12 hours later at U, 16 hours later at T, and 20 hours later at R That is to say longitude and time are strictly proportional in the ratio of 360° to 24 hours or 1° to 4 minutes, of time Hence it appears that every point on the earth's surface has its own particular or *local time* that every point in the

same longitude has the same local time, and that one point to the west of another has local time later than the first, one east of another has local time earlier

We may note here that the civilized world finds it inconvenient that each place should employ its own local time for ordinary use, the effect upon, *e g*, the compilation of Bradshaw may be imagined A system of *standard time* and *time zones* is gradually coming into general use, each zone being 15° of longitude or one hour of time in width Thus we have western European time, based on the local time of Greenwich on longitude 0°, mid European time an hour earlier on longitude 15° E, eastern European time two hours earlier on longitude 30° E The meridian of 30° E also holds for Egypt and South Africa North America has Atlantic Eastern, Central, Mountain, and Pacific time, based on the meridians 75°, 90°, 105°, 120°, and 135° W longitude

To determine the longitude of a place it is only necessary to compare a watch set accurately to local time with one set with similar accuracy to a standard time Local time can be simply ascertained by observing the time of transit of stars or the sun across the meridian of the place, or it may be deduced from observations of altitudes of these bodies when they are "off the meridian" Comparison of the local time with the standard (*i e*, the local time of a place of known longitude) can be made with great accuracy by means of the telegraph, with somewhat less accuracy by a series of chronometers (the method used on board ship although now assisted by wireless telegraphy) and with little accuracy by observations of certain independent celestial occurrences, which can be predicted but are not easy to observe In the last case we may observe the eclipses of Jupiter's satellites, the occultations of stars by the moon or even the distance of the moon from certain stars, and we can calculate that when these things "happen" it is such and such a time at (say) Greenwich, we record the local time

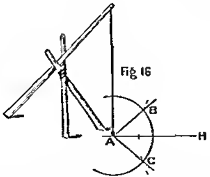
when we see them happen, and so get a means of comparison

The North and South Line —It being now (p 17) understood that the north and south line at any place is the meridian of longitude passing through the place and the north and south poles, the advantage of reckoning azimuth from this direction will be apparent The north and south line can be accurately found in a place of known longitude, by observing transits of stars or the sun across the meridian, these bodies being either north or south of the observer at the known instant of transit, or it can be calculated from the same observations of altitude "off the meridian" as are used for finding local time

But a number of approximate methods are more generally useful to the reader as distinct from the maker of maps, the chief need being to set or "orient" the map so that the top will be towards the north and the bottom towards the south

A In the daytime

Method 1 Some time before noon fix a pole in the ground at a slope. Hang a plumb-line from the top of



the pole, as at A, Fig 16 From A draw a circle well within the end of the shadow of the pole Note the point where the end of the shadow, as it shortens, crosses the circle, as

at B The shadow will continue to shorten till the sun reaches its highest point at noon when it will begin to lengthen again, as in the dotted line Mark the point C where it crosses the circle for the second time Draw lines A B, A C, and bisect the angle B A C by the line A H A H is the north and south line

Method 2 A rough method familiar to scouts

In the Northern Hemisphere—Place a watch on its back and turn it round till the hour hand points to the sun A line bisecting the angle between the hour hand and the figure XII points southwards

In the Southern Hemisphere—Turn the watch till the line joining the centre of the face and the figure XII points to the sun *A line bisecting the angle between this line and* the hour hand points northwards

Note that quite roughly, the sun is

to the S	in the northern hemisphere		} at noon
N	„ southern	„	
S E	„ northern	„	} at 9 a m
N E	„ southern	„	
S W	„ northern	„	} at 3 p m
N W	„ southern	„	
E	*in both hemispheres at* 6 a m		} if above the horizon
W	„ „	6 p m	

B At night *Northern Hemisphere*

For rough purposes the pole star may be taken as due north It can be found by producing the straight line joining two stars in the constellation of the Great Bear, known as "The Pointers" (1 and 2, Fig 17) The pole star is precisely north *i e*, on the meridian in the little circle it describes, when the star 3 in the Great Bear is directly above or below it, this fact may be taken advantage of for accurate observations

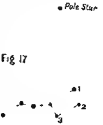


Fig 17

The Compass.—The compass needle does not in general point true north and south but in directions known as *magnetic* north and south. True direction and magnetic direction may differ by quite large angles; the difference at any place is known as the *magnetic declination* or the *variation of the compass*. Charts are published showing the declination (which varies from year to year) in different parts of the world, but it is always well to ascertain the declination by finding the true north and south lines by one of the methods just given and comparing with magnetic directions. Compasses are also liable to deflection by local attraction, due to iron in the ground and other causes and they cannot be depended upon on land to the extent that is safe at sea.

CHAPTER II

Map Construction

Maps.—The material for a description of any part of the earth's surface consists, as we have shown, of a *survey* in the form of *records of observations of altitude and azimuth*, elevation and slope, at a number of points connected together by means of *triangulations and traverses*. Such records are unintelligible until the results are exhibited graphically as a diagram or map, and we have now to consider how such a diagram is to be constructed and read. Let us think first of a quite small part of the earth's surface, and suppose it to be truly plane and horizontal. It is evidently quite easy to "plot" the numbers from a triangulation or traverse in the manner shown in Figs 6, 7, or 8, the first question—a very important one—being What relation is the map to bear to the actual size of the ground? This relation is called the *Scale* of the map, and upon it the whole usefulness of the map depends.

The scale of a map is usually expressed in one of two ways. We may say that a certain length upon the ground is to be represented upon the map by a fixed fraction of that length—say one hundreth, or one thousandth, or one-millionth; or to put it otherwise, a given length on the map is to represent a hundred, or a thousand, or a million times that length on the ground. Hence we get a fraction ($\frac{1}{100}$, $\frac{1}{1000}$, $\frac{1}{1,000,000}$, and so on), which indicates the *natural scale* of the map. This fraction, which has the advantage of being independent of all arbitrary units such as inches, *feet, miles, kilometres, versts, and the like, and is therefore* equally intelligible in the maps of all nations, is often called the *Representative Fraction*, or R F of the map.

The second kind of scale is an *artificial scale*, inasmuch as it requires the use of two arbitrary units We may say that the scale is so many inches to a mile, meaning that, *e g*, one inch on the map represents one two six or twenty miles on the ground Foreign maps are not, in general, much troubled by artificial scales since the unit on the map is usually the millimetre or centimetre and that on the ground the kilometre, giving a simple fraction for the corresponding natural scale

As there are 63,360 inches in a statute mile, the natural scale of one inch to the mile is 1 63,360 The representative fractions for various numbers of inches to a mile and miles to an inch can be found by very simple arithmetic and the reader is recommended to calculate out a few cases and remember some of the results, so that if he is accustomed to think in the artificial scale he will not be thrown out by a foreign map showing only a natural scale or an artificial scale with unfamiliar units

Construction of Scales —The construction of artificial scales, for large-scale maps at least, is a simple matter if we remember that for ordinary use it is convenient to draw the scale on a line somewhere about 6 in long As an example, suppose we want a scale to show yards for a map whose natural scale is 1 15,120

1 in on the map represents 15 120 in. on the ground = 420 yds

6 in on the map would represent 2,520 yds. on the ground

Let us draw the scale to represent the convenient length of 2,500 yds Then, by simple proportion,

$$\frac{2\,500 \text{ yds}}{420 \text{ yds}} = \frac{x \text{ in}}{1 \text{ in}} = 5\ 95 \text{ in},$$

or 2,500 yds is represented by 5 95 in

Draw a line A B 5 95 in in length (Fig 18) Draw any other line A C and along it mark off with the dividers

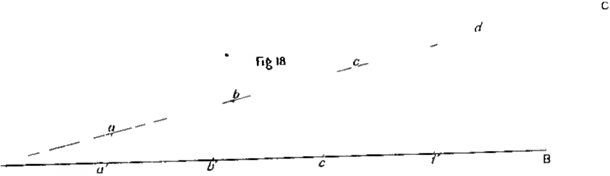
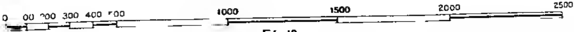


Fig 18



Scale of Yards

Fig 19

5 equal parts at $a\ b\ c\ d$ that would approximately divide the line A B into five Join B C, and through $d\ c\ b\ a$ draw lines parallel to B C, cutting A B in $d\ c\ b\ a$ Then A B is similarly divided into 5 equal parts, each of which must represent 500 yds The part A a can be subdivided in the same way into 5 equal parts, and we get divisions each representing 100 yds The finished scale is shown in Fig 19

More elaborate scales for special purposes can be con structed by precisely the same method We give two additional examples

(1) Draw a scale of paces (1 pace = 30 in) for a map whose natural scale is 3 in to a mile

The natural scale of the map is 1 21,120

1 in represents 704 paces,

6 in „ 4,224 „

Take 4,000 paces, then

$$\frac{4,000}{704} = \frac{x}{1} = 5\ 68 \text{ in}$$

Draw a line 5 68 in in length, and subdivide as before into (say) 8 equal parts, each representing 500 paces

(2) A horse trots 8 miles an hour Draw a time scale for a map whose natural scale is 1 200,000

1 in represents 200,000 in

6 in „ 1,200,000 in

But one hour's trot represents 63,360 × 8 = 506 880 in We take, to get the convenient length of scale, two hours' trot, which represents 1,013,760 in Then

$$\frac{1,013,760}{200,000} - \frac{x}{1} = 5\ 07 \text{ in}$$

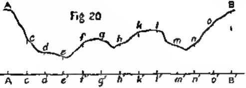
Draw a line 5 07 in in length, divide into 12 parts Each division represents the distance trotted in ten minutes

It is well to note that

1 kilometre = 3,282 ft,

1 verst (Russian) = 3,500 ft

The Representation of Heights — In describing the methods of plotting the observations of a survey (page 10) we restricted ourselves to the case of a horizontal plane The altitudes being all equal only azimuths *and distances had to be taken into account* Where *the* ground slopes and more especially where the gradients are different in different directions it is evidently impossible to make a diagram or map directly from the distances The map is to be in some way a picture or bird's-eye view of the ground represented and slope must clearly be taken into account But a map must be drawn upon flat paper the only alternative is a model which is always clumsy and expensive Suppose for example the observer is standing at the edge of a sheer precipice a mile high and that a way from the precipice the ground is level *or slopes gently we cannot represent the mile from* the top of the cliff to the bottom in the same way as a mile from the cliff top along the plateau The map has to be in fact, a picture or *projection* of the irregular surface upon the horizontal plane and we must find some other means of representing the irregularities or *relief* of the surface-configuration



This will be most easily understood by considering a line along the ground joining two points which we may call A and B Imagine the ground to be cut vertically along this line down to datum level Then the severed *edge would show the rise and fall, as for example* A B in Fig 20 and the projection of A B on the horizontal

plane (an edge of which is shown by the line A B) would be the distance to be represented to scale on the map The points *c d' e' f' g h k l m n' o* would represent corresponding intermediate points *c d e f g h k l m n o* on A B Any distance on the ground is therefore projected on the horizontal plane, and the "horizontal equivalent" (*page 15*) *is drawn to scale on the map*

It will be seen that in the case of surveying by triangulation this greatly simplifies the processes necessary for map construction Referring back to Fig 7 (page 11) if we plot the horizontal equivalent of the base line A B

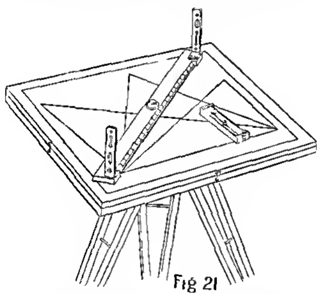


Fig 21

only the azimuthal angles at A and B and other points need be taken into account, the altitudes do not require to be considered at all until the question of levels arises Advantage of *this simplification* is taken in the graphic method of surveying with the *plane table* (Fig 21)

This is merely a drawing board mounted on a tripod stand The board is set up, say, at A, and levelled A point *a* is marked on the paper to represent A, and a flat ruler with sights (called an alidade) is placed on *a* and turned round until B is visible through the sights A line is then drawn in the direction A B, and a length *a b* measured off to represent the horizontal equivalent of A B on the desired scale of the map Next the alidade is placed on *a* in such directions that C, D, F, G, and E appear successively through the sights and lines *a c*, *a d* *a f*, *a g*, *a e* are drawn in their directions The plane table is then transferred to B, levelled and the alidade being placed along the line *a b*, the board is turned round till A is seen through the sights, it is then clamped Rays *b c*, *b d*, *b e* are then drawn in the directions of C, D, and E, and the intersections of these lines with those previously drawn from *a* give points *c* *d* *e*, which (by "similar triangles") are the proper representations to scale of C, D E In the same way the plane table may be set up at D and E and intersections *f* and *g* obtained, and so on for the whole triangulation

This graphic method is largely used for rapid work in the field The map grows under the hand of the surveyor, and details of all sorts can be "sketched in" as he goes along On the other hand, the stretching and shrinking *of the paper with changes of weather and other cir*cumstances make it impossible to attain the accuracy required in primary triangulation We may suggest that every student of geography should make it his business to obtain some practice in plane tabling, no matter how rough the available equipment may be (Distances can be measured in paces)

Contours —The map being then a projected representation of the ground, it is necessary to find some method of indicating the surface relief The fundamental idea under

lying every method of doing this is that of connecting all points on the ground in the same horizontal planes by lines passing through them. Such lines are called *contour lines* or *contours*. The surface of the sea being horizontal its waters meet the land in a line which fulfils the conditions: a *coast line* is therefore a contour, and if we take the mean level of the tide the coast line is the contour of mean sea-level. Imagine now the waters of the sea to rise 50 feet, there will then be a new coast line 50 feet higher than the old, and coincident with a contour 50 feet above mean sea level. By the methods of levelling described above, it is evident that series of points can be found for any heights above sea level, and so contours can be drawn at convenient vertical intervals, 50 ft, 100 ft, 500 ft, and so on, according to the nature of the country. The method of drawing contours employed in practice is to mark down, in their proper positions upon the completed outline, a number of points at the same height—as determined by levelling—and then to sketch in the contour line passing through these points, having regard to the visible relief of the ground. The number of such points required is determined by the degree of precision of the survey. Rough contours can be quickly added to a plane table sketch with the help of quite a small number, while the levelling of a line of railway or a drainage system demands the highest accuracy attainable.

Contours of the bottom of the sea can be drawn by means of points obtained by soundings. Such contours are known as *isobathic lines* or *isobaths*.

The general principle of drawing lines through all points on a map having the same value of some element is capable of wide extension. The lines are generally called "iso-" lines or *isopleths*. Thus lines passing through all points having the same barometric pressure are called *isobars*, *isothermals* pass through points having

the same temperature, *isonephs* the same amount of cloud and so forth. What we have to say about contours and the reading of contour maps applies *mutatis mutandis* to all isopleths.

The adequacy with which contours represent the configuration of any piece of ground depends upon the vertical interval between the lines: the smaller the interval the more complete the representation. In Fig 22 for

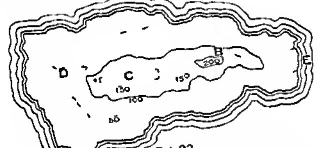


Fig 22

example contours at a vertical interval of 100 ft (solid lines) show an island rising to a hill with a summit at B 200 ft above sea level. But the insertion of 50 ft contours (dotted lines) reveals the facts that there is a second summit C to the west of B rising to something over 150 ft, and a pass or *col* (see page 57) between B and C; that there is a low-lying valley D on the western side of the main mass; and that the eastern end of the island is a low cliff E 50 ft high. The 100 ft contours are quite accurate but as it happens they miss all these points. It may be supposed that other minor features would be disclosed if contours were drawn at intervals of 25 ft or 10 ft. The appropriate contour interval for any map depends on the nature of the ground and on the purpose for which the map is intended. Ten

foot contours would be useless and illegible on a map of the high Alps, while for military manœuvres in open country they might be invaluable The large scale Ordnance maps of this country show contours for every 100 ft, and one of the most frequent occupations of the military surveyor in time of peace is the insertion of intermediate lines on special sheets The main fact to keep in mind in *interpreting contour maps* is that the map tells us nothing about the ground between two contour lines except in a quite general way If we have a vertical interval of 100 ft, any point between (*e g*) the 100 ft and 200 ft lines may be 101 ft or 199 feet We cannot be more precise, unless (as is sometimes done) auxiliary *form lines* are inserted to indicate special features, or actual *spot-levels*—figures giving the exact heights of such points as hill tops—are printed in

Relation of Contours to Slopes —The relation of contour lines on the map to the slope or gradient will be seen at

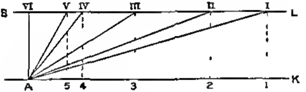


Fig 23

once from Fig 23, which represents a section of the same sort as is shown in Fig 11 Let A K represent (in section) the horizontal plane, A being a point, let us suppose, on the coast Let B L represent (also in section) another horizontal plane at the vertical height of the first contour, say 100 ft Let A I A II A III, A IV, A V, A VI represent varying degrees of slope of ground upwards from A Then the 100 ft contour will occur at 1 in the

case of slope A i, at 2 in A ii at 3 in A iii, at 4 in A iv, at 5 in A v, and at A itself in A vi, which is a perpendicular cliff. That is merely to say that the steeper the slope the shorter the distance we have to travel on it to ascend 100 ft or, in other words the steeper the slope the closer the contour lines are together. A level plain has no contours, or the contours are infinitely far apart, while in a precipice all the contours run into one another.

We have to notice that slopes must be reckoned directly across the contours, i.e., along the steepest line. In Fig 24, which represents contours on a slope 300 ft high, the true gradient is the line A B. An easier ascent may be achieved by taking the slope obliquely along A C as a horse or cyclist does in "quartering" a hill, but A C has no relation to the real steepness. As the line A B is that along which water would flow, it is sometimes called a *stream line*. The directions of stream lines are often difficult to follow in cases of curved or irregular contours, and their study is an important matter in learning map-reading.

Fig. 24

Since steepness of slope is indicated by distance between contours reckoned along stream lines, the average gradient in degrees between any two contours can be easily ascertained by measuring the horizontal distance between them on the map, and converting this into feet (or other unit) by using the scale. This gives the horizontal equivalent for the known vertical interval, and the angle can be found by the method explained on page 15.

The conditions resulting from changes of slope between two points on the map are often important, as for instance in determining whether the one point can be seen from

the other or not Let A and B Fig 25 represent the two points in section The line of sight between them is the straight line A B If the surface of ground between is on the whole concave in slope

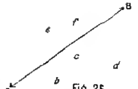


Fig 25

as shown by the line A *b c d* B A and B are intervisible while if the general slope is convex as shown by the line A *e f* B they are not If the surface is fairly regular concavity will clearly mean that the slope is steeper near B than near A and convexity that it is steeper near A than near B That is if the contours are closer together near B than near A as in Fig 26 (*a*) A and B are intervisible if they are closer together near A than near B as in *Fig 26 (b) they are not* But we must be sure that *underfeatures* like *c* (Fig 25) do not rise high enough to intervene

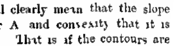


Fig 26a

Fig 26b

Matters of this kind present some difficulty to the beginner in map-reading but skill is quickly acquired by practice In doubtful cases a section should always be drawn This is easy to any one accustomed to plot "graphs" of any kind Join the two points A and B (Fig 27) on the contoured map by a straight line

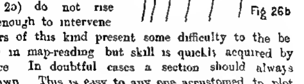


Fig 27

and on a sheet of ordinary squared paper take the lower point (A) as origin, reckon heights as ordinates and distances as abscissae Plot the points where each contour is crossed by the line A B, measuring distances from A Draw a curve freehand through the points so

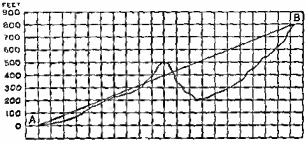


Fig 28

plotted, and a straight line from A to B The result is a diagram (Fig 28) similar to Fig 23, and conclusions can be drawn accordingly *The student is warned that* the "drawing of sections," which is not a geographical exercise, constitutes a popular form of question in some examinations in geography

Hachures and the Layer System.—It is not easy, except after long practice, to gain a clear impression of the real relief of a region from maps showing contour lines alone, especially if the vertical interval is considerable Some maps yield excellent results without any further device, notably those of the United States Surveys (see the Survey's *Topographic Atlas*), but it is usual to employ some method of making the map tell its own story more forcibly These methods follow two main lines Predominance is either given to the slope of the ground, its height above sea level being regarded as of secondary importance, or the height is considered first and the slope left to be inferred

In the first case, the contoured map is converted into a picture by drawing stream lines between the contours at distances apart proportional to their length, i e, the steeper the slope, and therefore the closer the contours the closer the stream lines are drawn together as in Fig 29 Steep slopes are thus darkened by a close array

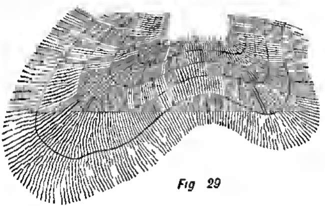
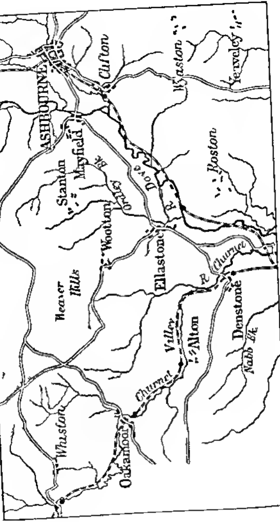


Fig 29

of stream lines, while gentle slopes are left white This method lends itself to many degrees of refinement The contours can eventually be removed and the close stream lines replaced by *hill shading* till we get the effect shown in Fig 30 The highest expression of this method, which in its cruder stages is known as *hachuring*, is probably to be found in the 1 100,000 "Dufour" map of Switzerland, although there are many excellent examples in other modern maps The limitation is that while the slope of the region represented appeals at once to the eye, no indication of its height above the sea is conveyed On a map of the British Isles parts of the central plain of Ireland and of the plateau of the Scottish Highlands would appear the same The hachuring system employed in good maps


ASHBOURNE
Clifton
Wyaston
Yerveley
Mayfield
Stanton
Dove
R.
Roston
Wootton
Ellastone
R. Churnet
Churnet
Weaver
Hills
Denstone
Alton
Valley
Nabb Bk
Churnet
Whiston
Oakamoor

Fg 30

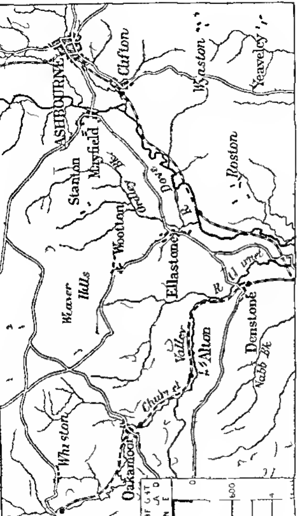

ASHBOURNE
Clifton
Wyaston
Yeaveley
Mayfield
Stanton
Roston
R. Dove
Wootton
Weaver Hills
Ellastone
Denstone
Nabb Bk
Alton
Valley
Whiston
Oakamoor

Fig 31

must not be confused with the arbitrary "caterpillar" representation of mountains, now fortunately obsolete

The second device to be considered is that of *layers*, which consists in giving the interval between each successive pair of contours a distinctive colour, as in Fig 31 Bartholomew's ½ in to a mile (1 126 720) "cycling" map of Great Britain is an excellent example see especially such sheets as the Cairngorm district of Scotland *Here all regions below 100 ft above sea level are coloured* a dark green regions between 100 to 200 ft a lighter green, 200 to 300 ft a yet lighter green, 300 to 400 ft a lighter green still, 400 to 600 ft a light brown 600 to 800 ft a darker brown, and so on In these maps height above sea level (an essential factor in most geographical discussions) asserts itself at once, but slope has to be inferred from the narrowness or width of the colour strips Also if the vertical interval is at all close, either the variety of available colours gives out, or the map becomes expensive by reason of the number of printings and the high degree of skill required to ensure accuracy It is true that, in general, the higher the elevation becomes the steeper is the general slope of the ground, but a contour map with varying vertical intervals between the contours, as in this case, is always somewhat misleading

Many recent maps combine the hachuring and layering methods, often with results which appeal at once even to the inexperienced map reader Examples from the ½ inch map of the Ordnance Survey and the popular "picture post card," may be referred to

Map Projections—Up to this point we have supposed ourselves to be dealing only with large scale maps of a small portion of the earth's surface (page 26) When the map covers a considerable area—and the more accurate it is to be the smaller that area is—we are confronted with

the difficulty that the earth is a sphere and that the covering of a sphere cannot be opened out into a flat sheet without stretching it, and so distorting it or tearing it the sphere the spheroid and the geoid present what mathematicians call ' undevelopable surfaces

The devices employed for getting over this difficulty are commonly called *projections* but it would be better in most cases to call them *developments* for few of them are really projections in the mathematical sense Suppose we take a tennis ball and draw on it an outline map of the world We can place in contact with it a flat sheet of paper as in Fig 32 At P, the paper being in contact with the tennis ball the point on the ball would be transferred directly to the paper All other points on the ball would be represented on the paper by points the positions of which would depend upon the point of view, the ' point of projection Let us suppose the

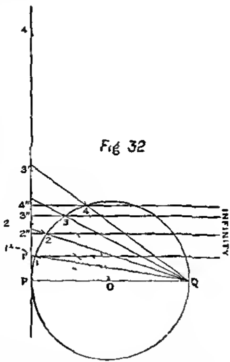


Fig 32

arcs between P 1 2 3 and 4, on the sphere to be equal If O were the p int of view the points 1 2 3 4 would be represented on the sheet of paper by 1, 2 3 4 This would give us what is called the *gnomonic* projection, which has the property (useful to modern navigators) that *great circles appear upon the map as straight lines* If Q were the point of view we should get the *stereographic* projection in which all angles on the globe are represented by equal angles on the map directions or azimuths, and consequently outlines over the globe are *correctly delineated on the map and circles on the* globe great or small, are circles on the map If we remove the point of view to an infinite distance the lines of projection become parallel and we have the *orthographic* or picture projection with points 1 2" 3 4" *This last projection is of little use except for pictures of* the moon as we see it—from an infinite distance

We can enclose the sphere in a conical paper bag as shown in Fig 33 The sphere will obviously touch the paper along a line, and on this line the representation will be correct, but on either side of it *inaccuracy will increase* to an extent and in a manner depending on the system of projection on the inside of the cone Thus we have a whole group of *conical projections and the cone* can be afterwards opened out flat

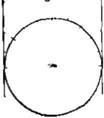
Fig 33

The perspective projections described above are merely the case of conical projections in which the apex of the cone A (Fig 33) touches the sphere itself, as at A in the same figure In the same way we can think of the case where the apex of the cone *(A) is removed to an infinite* distance *from the sphere* and its sides become parallel Here we have the group

of *cylindrical projections* as in Fig 34 in which the dotted lines would indicate a gnomonic projection on a cylinder

But in the construction of maps the underlying mathematical considerations are questions for the expert they are not often included in any of the simple cases mentioned *What matters to the reader* of the map is the special property of the map with regard to accuracy Accuracy can be secured in any map in any one of three kinds but no map can be accurate in more than one We may have—

Fig 34



(1) Accuracy, or consistency, in regard to distances measured from a point in different directions

(2) Correctness in representation of azimuthal angles or directions and consequently of outlines

(3) Equivalence as to area in different parts of the map

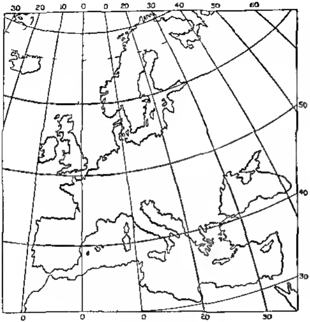
In the first case distances measured from a fixed point *in any direction are represented on equal scales* We may have, for example, a map of a hemisphere with Cape Town in the centre the distances to New York Bombay, Rio Janeiro Melbourne will be shown on the same scale Projections of this kind are not very much used A good example is *Postel s radial projection*

The second case needs no further explanation We have already had a specimen of the type in the Stereographic and another familiar *example is Mercator s* map, which is not a projection at all but a development following certain mathematical rules Mercator s map was originally devised for coastal navigation and *rhumb line* sailing because the bearings being correct, it is only necessary to join two points

on the map and find the azimuth with a protractor in order to get a true course for sailing from one to the other. The course so found is longer than the great circle route joining the two points but the difference only affects the refinements of modern navigation which can be met by the use of the gnomonic projection. A Mercator map should never be used for purposes in which comparative area is important (as in a map showing the relative areas included in the British Empire) for the scale varies enormously. Greenland, for example, appears about the same size as South America.

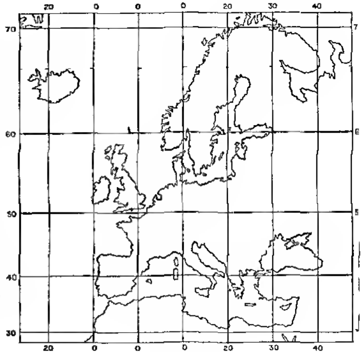
Equal area maps commonly show much distortion but they are of great value and their legitimate use has been much extended in recent years. Their special merit may be explained by saying that on a map of the world a halfpenny will cover the same number of square miles whatever part of the map it is placed. The most familiar examples are *Lambert's azimuthal equal area projection* and *Mollweide's projection*. Examples of the three types of map described will be found in Figs. 34*a*, 34*b*, 34*c*.

Conventional signs.—It is necessary on large scale maps to have the means of indicating certain features or structures which cannot be actually represented, such as *fenced and unfenced roads, railways, cuttings, embankments*, woods and the like. For this purpose *conventional signs* are employed. Those used in British Ordnance Survey maps are illustrated in a characteristic sheet (published by the Survey, price 6d.). The examples given in Fig. 35 are the conventional signs chiefly used



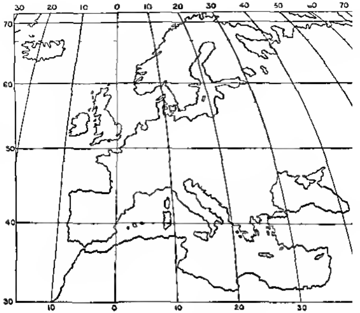
Poste s Rad Map

F g 34a



Me cato s Map

F g 34b



Mollweide's Homalograph c Map

F g 34c

F g 35

CHAPTER III

Map Reading

Scale.—In deciding upon the map to be used for any specific purpose, the first thing to be considered is the scale. Where land is of high value, as in the central parts of great cities, every square pole is important in any business of buying and selling, and we need a map showing the smallest details with accuracy. Thus, apart from special private surveys, we have the Town Plans of the Ordnance Survey on a scale of 10 ft. to a mile. On enclosed agricultural land, and even in the suburbs of towns, most *of the sheets of a map on this scale would be altogether* blank, and a scale of 1 : 2,500 (nearly 25 in. to the mile) is *large enough*; *the Ordnance map on this scale is the* largest published for the whole country. For many purposes concerning estates, or small districts such as parishes and the like, the scale of 1 : 10,560, or 6 in. to the mile, is convenient, and the Survey provides a map on this scale. Comparing a sheet of the 6 in. map with one of the 25 in., we observe that a large amount of detail has been rejected, and the choice between selection and rejection for any scale demands the highest skill and judgment on the part of the draughtsman.

Maps on these scales may be looked upon as "stationary" maps: they delineate certain areas, but are not of much service in indicating the relative positions of points not near together or the routes joining them. We cannot imagine a pedestrian providing himself with a set

of six inch sheets for a walking tour On the other hand, detail becomes less and less important as the rate of locomotion increases, and so the generalization of the *smaller scale maps is no disadvantage while the relative* positions of different points and the distances between them are shown for wider areas as the scale diminishes We may say, for instance, that 1 63 360 is a convenient scale for a "walking map 1 126 720 (half that size) for a 'cycling map and 1 253 440, or 4 miles to the inch, for a motoring map The scale of 1 500,000 *about 8 miles to the inch, exemplified in* maps of France and Germany, shows main routes well, but cross country roads become confusingly intricate

Coming to still smaller scales, we have maps which serve chiefly to show the wider aspects of distribution over large areas, such as the general features of configuration, geological structure, distribution of temperature or vegetation density of population, and so on *Here the area is usually sharply defined*, and we have a struggle between excessive generalization and unwieldy size in the map Taking the ordinary hand maps of the larger atlases, we find the following scales of common occurrence —

England and Wales—1 1,700 000
British Isles—1 2,500 000
German Empire—1 3 700,000
Europe—1 15 000 000
Asia—1 30,000 000
Africa—1 25,000 000
North America—1 25 000 000

but it must be remembered that in the larger areas the scale varies in different parts of the map according to the projection and maps of the world, shown in hemispheres *or otherwise, can* scarcely be said to have a scale at all

Surface Relief.—After an appreciation of scale the next and much more difficult art the map-reader has to acquire is that of understanding surface configuration or relief. Here we have to bear in mind that contours aided by hachuring, hill shading or layers constitute a conventional system, and that we can give to the system any value we please. Vertical distance has for all natural and artificial conditions a significance vastly greater than horizontal distance. The highest peak in the world rises only $5\frac{1}{2}$ miles above sea level, a distance imperceptible upon any reasonably sized map of Asia, yet a ridge half a mile high may change the geography of a whole continent. A relief model having the same vertical and horizontal scales is about as rough as an orange: hence to gain a true idea of relative importance in almost any sense we must in imagination greatly exaggerate the vertical scale. It is for this reason difficult to understand the strenuous objection urged by many geographers to some of the relief models easily obtainable in which the vertical scale is *considerably greater than the horizontal*.

Admitting the paramount influence of relief, we must attach great importance to a study of it. The examination of maps results in the classification of contours into a quite small number of groups representing certain units of configuration or *land forms*. Much confusion has arisen from trying to associate the land forms defined in this way from an arbitrary mathematical convention with the causes of their origin, which may be widely different in identical forms. These causes are matters for the skilled geologist, and do not strictly concern the map reader. Following Mill we may arrange the simpler land forms and their geometrical consequences in a short list.

A *plain* is a flat and nearly horizontal surface of land. A tilted or inclined plain forms a *slope*, but slopes are not necessarily plains, for the degrees of inclination may vary

and the slope become convex or concave (see Figs 25 to 28)

Two diverging slopes (*i e* two slopes on which objects would roll away from one another in opposite directions) meet in a line called a *Divide Water Parting*, or *Watershed* Converging slopes meet in a *Valley line* or *Thalweg* It is clear that rain falling on the surface of land will be collected within areas bounded by divides or watersheds, and each of these areas will be drained along the valley line, which forms the course or bed of a *river* The area enclosed by one divide is called a *Basin* or *Drainage Area* In most cases the divide is not a closed curve but touches a coast at two points the valley line then also reaches the coast and the river (if there is one) draining the basin flows into the sea In Fig 36 the dotted line A B represents the divide, the solid line D C the valley-line, and A B the coast included

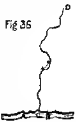


Fig 36

Where the divide forms a closed curve, as in Fig 37, the basin forms a *Hollow* Surface water will drain to the lowest point P of the valley line If the amount of water received by rainfall is greater than that lost by soakage and evaporation, the hollow will fill up to the level of the lowest point of the divide, forming a lake and drainage into another basin will occur but if as much water is lost as is received, as in arid regions, no water passes out of the basin, which then forms an *inland drainage area* In many inland drainage areas the balance between gain and loss of water is so adjusted that

Fig 37

there is an accumulation of water round P either perennially or during wet seasons, but not in sufficient quantity to fill the hollow up to the point of overflow Lakes formed in this way are usually salt, the soluble materials washed down being deposited as evaporation goes on (as in the case of, *e g*, the Great Salt Lake of Utah)

River basins occur in the greatest possible variety of forms, primary or major basins being usually sub-divided into secondary or minor areas of the same type, with *sub-divides* and *tributary* valley lines ABCDEFG, Fig 38, represents a primary basin I I the primary valley line B *b*, C *c*, D *d*, E *e* F *f* are secondary divides, and 2 2, 3 3, 4 4, 5 5 tributary valley lines Evidently tertiary systems will also occur within the secondary basins, *c* C D *d*, for example, may have subordinate systems within it, as shown in the figure and so on indefinitely

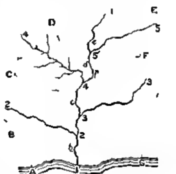


Fig 38

It is desirable, but not always easy, to fix major

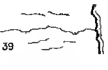


Fig 39

directions within drainage areas In the case of an area like that shown in Fig 39 the problem presents no

difficulty The great length of the basin compared to its width makes the main valley line unmistakable, and this direction is called the *longitudinal* direction Sub divides and tributary valley lines following this direction are also said to be longitudinal (solid lines in the figure), and those departing from it by more than 45° are said to be transverse When the basin is circular, or, still more, when it takes a form like the Great Valley of California (Fig 40), the division into longitudinal and transverse is not so easy The line of the valley which reaches the lowest point of the basin (usually the one which reaches the sea) strikes the dominant note, and serious difficulties rarely arise In Fig 40 A B is clearly longitudinal, A C and A D are as clearly transverse

Fig 40

When a slope is steep and its length extends for a great distance compared with its height, it is called an *escarpment* or *scarp* Scarps are commonly associated at their bases and summits with either gentle slopes or plains A gentle slope at the base of a scarp very often converges with the scarp, forming a valley line, hence we have the condition of part of a basin with its longitudinal valley line close to a major longitudinal divide, the transverse lines on the scarp side slope steeply, while those on the other side slope gently The slope at the summit usually diverges at a relatively small angle, forming a divide along the crest of the escarpment There may, however, be two diverging scarps close together, forming a *Ridge* as in the "Hogs Back" between Farnham and Guildford

The escarpment is one of the most remarkable of all land forms, chiefly from its association with plains and slopes in the manner described An illustration of the

typical grouping is given in Fig 41 The broken lines are contours at vertical intervals of 100 ft A B is the main valley line at the foot of the scarp C D the main divide at the top It will be seen and herein lies the importance of this group of land forms that the plain at the foot of the scarp may be a region capable of supporting a large population A B is a slow flowing it may be navigable river but in flood time the

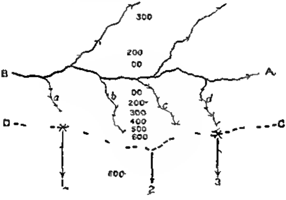
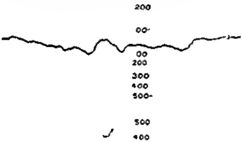


Fig 41

rapid streams from the scarp bring down quantities of *detritus* and deposit rich alluvium upon the plain near it perpetually renewing the soil Communication and transport from point to point across the plain are easy On the other hand the scarp itself is a serious perhaps insurmountable obstacle to intercourse between the inhabitants of the lower plain and another similar plain which lies beyond the crest Two examples of this characteristic arrangement may suffice the scarp of the Tibetan plateau coming down to the valley of the Ganges and the oolite escarpment in England In the latter case Fig 41 might represent a part of the Cotswolds

an l I lge H ll and B A the Warw cksh re Avon between Iewkesl ury an l a po nt below I ugly Typ cal ca es sl ou l be carefully stud ed so tl at the nature of tl e endless mod ficat ons wh ch arise n ay be under tood Compare aga n in England for example the ool te escarpment in its l fferent parts with tl e chalk escarpment

A steep slope having a con ex curve in the hor zontal plane forms a *sal ent* or *bl ff* Such features are of not infre juent occurrence along tl e l nes of escarpn ents tl ey appear on the map as shown in F g 42



F g 42

When the curve is closed and the total area surroun le l is small co npare l w l the l e ht we ha e tl e forms known as *n ounta ns* or *h ls* the arb trary l t nct n usually l l down be ng tl t a moun a n is a h ll in wl ch the slopes are more than 2 000 ft l gh If the total area c ere l s large in compar son w th the he ght the slopes may be surm unte l by an ele ate l pla n or *pl t au* M unta n l e n u ua ly tl e result of unequal destruct e a n upon the ra e l mas es of r d es or plateau occur e l er n l nes or *r nges* or n *gro ps* It sl ould be recogn sed tl at tl e gr up arrangement (sucl as is found in the h h ands of Scotlan l) is geo raph cally qu te as mportant as the l near Also t sl ould be po nted out

that a series of bluffs along a scarp such as might occur between the transverse valleys in Fig 41 is *not* a range of mountains although it may present that appearance fron the plain below The sky line of a mountain group as seen from a plain may also give the appearance of a range

The depressed part of a ridge between two mountains or hills gives a form which is concave in one direction and convex in the direc tion at right angles as in Fig 43 in which A B is con cave C D convex This is a *col* or *pass* or *saddle* and its re-cognition is specially important in map reading on account of its control of lines of com munications

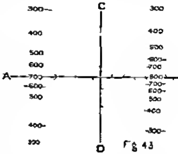


Fig 43

Referring again to Fig 41 we may obviously have a species of pass or col where the heads of the transver e valley lines of the scarp (marked *a b c d*) correspond with the heads of valley lines on the high slope (marked 1 2 3) as at the points X X If the lines on the high slope *alternate* with the transverse lines of the scarp as *b* 2 *c* in the figure then there is no such opening Compare in the case of the Cotswolds already mentioned the upper branches of the Windrush with the Evenlode (which lead over to the Stour a tributary of the Avon) or the Cherwell Openings of this kind and with them may be taken the overflow points of hollows (page 52) are usually called *gaps* (see on the maps such places as Goring Guildford Arundel Basingstoke Banbury etc)

A steep slope having a concave curve in the horizontal

plane forms a *Re-entrant* or *Cirque* (or *Corrie*). Cirques usually occur under somewhat special conditions at the heads of valleys which open out in the form of an amphitheatre as shown in Fig 44.

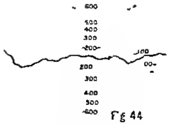


Fig 44

A perpendicular slope is known as a *cliff* or *precipice*, and is simply a particular case of the scarp. When two parallel precipices occur close together a *Gorge* or *Canon* is formed, the gorge being usually wholly or partly dry at the bottom (as the Khaibar Pass) while the cañon has a river flowing through it which makes access on foot impossible (as the Grand Canon of Colorado).

The student should pay a great deal of attention to the varying ways in which different land forms are grouped together in different regions. In a typical basin for example the valley line may descend steeply in one part and gently in another while the converging slopes change in steepness in a manner which has a certain clear relation to it. Take the case of a river rising on a plateau flowing down a scarp and crossing a low plain to the sea. We should have contours of the

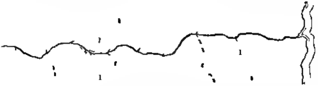


Fig 45

form shown in Fig 45. The relation would not be invariable but practice will soon make it possible to

recognise definite *types* of valley forms which will come eventually to be associated with special parts of basins or drainage areas, and so on for other forms

Lowlands, Uplands, and Highlands —For purposes like that just stated, it is often useful to arrange the various land forms together in groups depending upon the height above sea level at which they occur It is generally agreed for reasons which need not be discussed here, that the elevations of 600 ft and 2,000 ft above sea-level are the most appropriate boundaries All land between sea-level and 600 ft is called *Lowland*, between 600 ft and 2,000 ft, *Upland* above 2,000 ft, *Highland* These words may be applied to any of the land forms we have mentioned Thus, we have lowland plains, upland plains, highland plains, lowland valleys, upland valleys, and highland valleys Highland plains are known as *plateaux* Speaking quite generally, we may say that the average slope increases with elevation, the lowland plains include the greater part of the dry land area of the earth Considerable parts of the hollows are below sea level In this case the land is said to be *sunk* thus we have sunk plains

Many regions occur where land forms associated with one of these divisions are found in another The condition is probably to be ascribed to elevation or subsidence of the land, or to the action of some special agent such as glacier ice A highland or upland valley may suddenly terminate in a scarp or cliff forming a *Hanging Valley* discharging by a *Rapid* or *Waterfall* A lowland valley may have been submerged, forming an *Estuary* or an upland or highland valley, perhaps with a string of hollows once occupied by lakes, may have subsided, forming a *Ria* or (in the latter case) a *Fjord*

Similar divisions are recognized in the oceans From the sea surface down to 600 ft is the *Continental Shelf*

corresponding to the lowland, upon which uplands or mountains and plateaux may rise above sea level, forming *Continental Islands* (as the British Isles) Between 600 ft and 10,000 ft is the *Transitional Area* of steep average slope Beyond 10,000 ft are the vast dead plains of the *Abysmal Area*, upon which (in many places) isolated peaks or plateaux rise above the sea forming *Oceanic Islands*, as in the great groups of the south western Pacific

Lines of Communication —The lines of communication and transport shown upon a map are specially interesting because (apart from the practical importance of the routes represented) they throw a strong light upon the topographical features indicated by the contours But it is necessary to understand clearly at the outset the great influence which the mode of progression exerts upon the relation which exists between the routes and the topo graphical features

Wheeled vehicles are a comparatively modern in vention, nearly all transport was carried on upon the backs of men or animals until quite recent times and in going themselves from place to place men walked or rode But in animals we have the peculi arity that the maximum speed is low, and as it is approached the effort required becomes very great On the other hand, the ascent or descent of slopes, so long as they admit of walking, and climbing does not become necessary, does not reduce the speed very greatly below the rate ordinarily possible on the level, and this is true whether the animal be laden or unladen Even with a knapsack one takes a steep "short cut" in preference to "going round" Hence we find that the more ancient routes, pack-saddle routes, and even Roman roads (which were intended to provide a good service for movement of troops at their best pace), take a straight line as long as

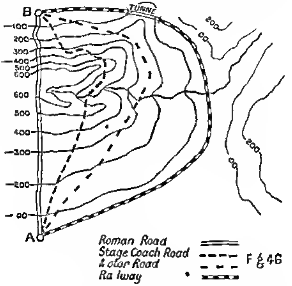
the slopes crossed are not more than about 20° and only "go round," or take the slopes obliquely, where the steepness is such that walking becomes really difficult

An animal can, however, *draw* a much greater burden than it can carry On the level weight does not come into consideration, and for wheeled vehicles it is therefore important that the route should be as level as possible Nevertheless, the difference between the maximum speed on the level and the minimum up the steepest practicable slope is comparatively speaking small and so although a slight *detour* is worth while, much time is lost if the deviation from the straight line is great The roads of the stage-coach period follow the Roman roads up to a certain point, and take a longer route when the older line becomes too steep

Mechanical traction in its commoner forms has the characteristic of high maximum speed and great power at high speed, but relatively small power at low speed the only exception is the traction-engine, which from this point of view is really an animal The characteristic is best exemplified in the case of the railway, which has its road all to itself, and need not be made to consider other modes of traction by means of a "speed limit" On the level the locomotive attains high speeds with very heavy loads, but a gradient a horse would scarcely notice brings it down to a very moderate pace Hence railways go miles round rather than face a quite moderate hill, and the consequent close adjustment of railway routes to land relief makes their lines extraordinarily useful in map study

The most recent phase of mechanical traction—the petrol-driven motor—marks a new phase in respect that enormous power can be applied to light loads Thus the motor can follow the Roman road if necessary, but it

c oc lo so eco om eal y ts stren₀th s n ts speed al hou l pec al con lerat ons l n t tl e full use of that jee l He e tl e de mo or road fol ows a l ne somewhere between tl e sta₀e coach road and the ra l vay The l ter l av n₀ tl rown tl e fo n er of these out of use for many je s tl ere s much road mprovement go ng on



F g 46 l ustrates the cond t ons of the d ffe ent routes bet veen two po nts A and B separa ed by a r dge 600 ft l and hav ng a fa rly st ll slope on the s do near A and a scarp o that towards B

T ra way be ng the most valuable type of route n re at on to topo₀ aphy t may be well to nd cate s genera relat o to certa n land forms ob er ng that the e hold good n d m n sl ng degree to motor roads s a₀e oac road and roads for pack saddle traffic

On a plain a system commonly forms a network of great complexity. The directions taken do not depend on the relief, for there is none, but on (a) the productiveness of the region—it may, for example, be a coal field—and (b) the period at which it was developed. With regard to (b) it may be said that if the region is in a 'new' country communication is probably almost wholly by railway, the short roads merely feed the railway at local points and are few and bad; whereas in an "old" (i.e. pre-railway) region they are relatively more important, although until quite recently their use as through routes has been lost. Compare regions of similar relief in England, the United States and South Africa.

When two plains are separated by a ridge or scarp the connecting routes make for the gaps (page 57), and there is no better instance of strenuous endeavour in this direction than the lines radiating from London to the Midlands of England, which have to cross first the chalk and then the oolite escarpments by gaps of varying degrees of accessibility and convenience. Study the half-inch map with the aid of Fig. 47. (Railway names before the 1921 Grouping.)

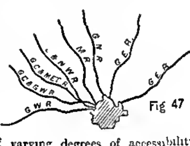


Fig. 47

More formidable ridges or mountain groups give as a rule fewer passes, and the concentration of the routes is more severe, the topographical control being more complete. The great railway routes out of Italy and the roads out of India furnish perhaps the best examples of this; see again the maps. There are of course exceptions, as in Ireland, where passes are mostly easy and direction rather than elevation controls the main lines.

Remembering (page 58) that in general the relief is steepest at great elevations the higher railways generally follow the valley lines for some distance, then alleviate the slope by cuttings and finally take the pass by a tunnel as shown in Fig 48 Examples of this kind occur constantly in the Alpine routes but they can be observed under more modest conditions in England note the Kilsby tunnel taking the London Midland and Scottish Railway over the oolite escarpment near Rugby—a great engineering achievement in its time

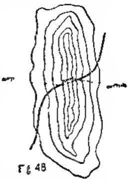


Fig 48

Where the valley lines on the two sides of a ridge or scarp do not correspond but alternate the crossing often becomes very difficult The problem may be solved by cutting and tunnelling as in Fig 49 but it is often possible to make use of a third basin as in Fig 50 by deviating for a comparatively short distance A good example of this is the line of the L M & S Railway between Leeds and Carlisle which ascends the valley of the Aire and deviates into the upper basin of the Ribble in order to get into the valley of the Eden

Fig 49

Fig 50

Main routes are often controlled by the land forms *occurring in coastal regions* If the coast consists of a broken scarp or line of cliffs the chief line has to keep away from it and important points on the sea are reached by branches, as in Fig 51 When the scarp is fringed by a coastal plain, the main line may traverse that plain and branches are thrown out to inland points, as in Fig 52 Amongst the best examples of the type shown in Fig 51 are the Southern Railway

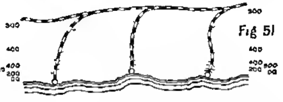


Fig 51

east of Exeter and the Great Western Railway between Exeter and the head of the valley of the Plym or the main line of the London and North Eastern Railway between Darlington and Berwick upon Tweed The

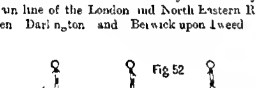


Fig 52

second type (Fig 52) is well illustrated by the Great Western Railway through Cardiff and Swansea and the

branches into the parallel valleys of the South Wales coal field

It would be easy to multiply examples of this kind, and to point out how the elaboration of the road and railway system in different parts of the world suggests the date of development and the stage attained, but it is unnecessary to carry the process further

NOTE

The following books which may be seen at any library, are recommended for further study —

TEXT BOOK OF TOPOGRAPHICAL SURVEYING. By C Close

HINTS TO TRAVELLERS Issued by the Royal Geographi Society

TREATISE ON SURVEYING By Middleton and Chadwi

TOPOGRAPHIC SURVEYING By H M Wilson

MAPS Their Uses and Construction By G J Morris

LEITFADEN DER KARTENENTWURFSLEHRE By Zoppritz

LE DESSIN TOPOGRAPHIQUE. By A Laussedat Very rai

HANDBUCH DER VERMESSUNGSKUNDE By W Jorda